Super Recognition in Development:

A Case Study of an Adolescent with Extraordinary Face Recognition Skills

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Abstract

Face recognition abilities vary widely in the population. While deficits in face recognition have been reported in childhood, it is unclear whether the full spectrum of face recognition skills can be encountered throughout development. This paper presents an in-depth examination of OB, a 14-year-old female with extraordinary face recognition skills: a “super-recognizer”. OB demonstrated exceptional face processing skills across multiple tasks, performing over 6 SDs above the mean for age-matched controls on the CFMT+, and significantly better than her peers on several other tests of face recognition. This level of performance is comparable to previously reported adult SRs. OB’s superior abilities appear to be specific to face identity: she showed an exaggerated inversion effect on several face recognition tasks, and her superior abilities did not extend to object processing or non-identity aspects of face recognition (emotion, age and gender). Finally, a task monitoring OB’s eye-movements demonstrated that OB spent substantially more time than controls examining the nose region of the face, a pattern previously reported in adult SRs. These results indicate that OB is particularly skilled at extracting and using identity-specific facial cues, supporting the hypothesis that face and object recognition skills are dissociable during development, and exceptional face recognition abilities can be detected prior to adulthood.

Keywords: super recognizers, face recognition, eye movements, individual differences, development, prosopagnosia.

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In the last decade an "individual differences" approach has emerged within the adult face recognition literature. Several studies have presented evidence that facial identity recognition skills can vary substantially within the typical population (Bowles et al., 2009; Wilmer et al., 2012), and this has been attributed to a variety of cognitive, social, personality and genetic influences. This approach has been bolstered by findings that some individuals represent the extremes at the two ends of the face recognition continuum. While reports of individuals with developmental prosopagnosia (DP), who have a severe and relatively selective impairment in face recognition, stretch back over 40 years (see Duchaine, 2011, for a review), much more recent work has identified so-called "super-recognizers" (SRs) who have extraordinarily good face recognition skills (Bobak, Bennetts, Parris, Jansari, & Bate, 2016; Bobak, Dowsett, & Bate, 2016; Bobak, Hancock, & Bate, 2016; Bobak, Parris, Gregory, Bennetts, & Bate, 2017; Robertson, Noyes, Dowsett, Jenkins, & Burton, 2016; Russell, Chatterjee, & Nakayama, 2012; Russell, Duchaine, & Nakayama, 2009).

This latter group of individuals have recently attracted a lot of interest, not only because of their theoretical importance to the advancement of the face recognition literature, but also as they may have a practical role in policing and national security. However, the few papers on super recognition that have been published to date have examined adults. Indeed, to date, very little work has investigated individual differences in face-processing skills during development (although see Bennetts, Murray, Boyce, & Bate, 2017; Croydon, Pimperton, Ewing, Duchaine, & Pellicano, 2014; Dalrymple, Garrido, & Duchaine, 2014; Johnston et al., 2011; Weigelt et al. 2014; for some indication of variability in face recognition performance across childhood). While instances of DP have been reported in children as young as four years old (e.g., Schmalzl, Palermo, Green, Brundson, & Coltheart, 2008; Wilson, Palermo, Schmalzl, & Brock, 2010), it remains unclear whether the full spectrum of face recognition skills can be encountered prior to adulthood. This is potentially an important question, given that it may provide unique insights into the development and maturation of the face-processing system. This paper reports an in-depth examination of the face-processing skills of an adolescent who firmly meets the adult criteria for super recognition. Initial investigations demonstrate the face-specificity of her skills, and a key eye-tracking study demonstrates that the ability may be underpinned by a specific scanning strategy that has previously been observed in adults SRs.

The focus of this investigation addresses a key theoretical debate in the face-processing literature: namely, whether developmental changes in face recognition performance reflect changes in face-specific processes, or more general cognitive development. Most authors agree that specialized strategies and neural systems underpin face-processing, and much evidence suggests these mechanisms come online at an early age and develop rapidly in the early years of life. In quantitative terms, behavioural work indicates a steady improvement in face recognition ability in childhood (5-11 years) (e.g., Bennetts et al., 2017; Croydon et al., 2014; de Heering, Rossion, & Maurer, 2012; Weigelt et al., 2014), followed by a levelling-off or dip in abilities during early adolescence (Carey, Diamond, & Woods, 1980; Chung & Thompson, 1995; Flin, 1980; Lawrence et al., 2008; Picci & Scherf, 2016), and subsequently slower but continued development from adolescence to adulthood. It is difficult to pinpoint the exact age at which face processing could be considered “mature”, but several studies suggest that this occurs relatively late in adolescence. For example, Picci and Scherf (2016) found significantly worse recognition performance in a group of 11-14 year old adolescents when compared to adults (18 to 25 years old). Likewise, Fuhrmann et al. (2016) examined face memory and face perception between the ages of 11 and adulthood, and found a significant difference between early and mid-adolescents (11 to 15 years old) when compared to older adolescents (16 to 18 years old) and adults. There was no difference between older adolescents and adults, leading the authors to conclude that face recognition was mature by 16 years of age. On the other hand, some researchers have suggested that face memory continues to develop even in early adulthood, perhaps up to the age of 30 (Germine, Duchaine, & Nakayama, 2011; Susilo, Germine, & Duchaine, 2013). These findings are supported by neuroimaging evidence that indicates the neural face-processing system continues to develop throughout adolescence (Aylward et al., 2005) and reaches maturity in adulthood (Golarai et al., 2007; Golarai, Liberman, Yoon, & Grill-Spector, 2010; Pallett & Dobkins, 2013; Peters, Vlamings, & Kemner, 2013; Scherf, Behrmann, Humphreys, & Luna, 2007; Scherf, Luna, Avidan, & Behrmann, 2011; Scherf, Thomas, Doyle, & Behrmann, 2013). Developmental changes in the neural face processing system are both structural and functional: for example, adolescents tend to show stronger activation of face-selective areas in the fusiform gyrus when compared to children (Aylward et al., 2005), but their neural adaptation to faces is not adult-like (Scherf et al., 2011); furthermore, the volume and selectivity of face selective areas in the fusiform gyrus increases with age throughout adolescence and into adulthood (Golarai et al., 2010; Scherf et al., 2007).

In sum, then, adolescents (particularly those around the age of 14-15 years) are likely to show poorer face recognition performance than adults, and this may be explained by immaturity of the neural systems underpinning face processing. However, one limitation to the studies presented above – particularly those using behavioural measures – is that many of them fail to discriminate between the development of face processing and the development of other abilities that might support face recognition (e.g., attention, ability to follow instructions, general memory, visual processing). In other words, it is unclear whether this pattern of development is face-specific, or reflects more generic cognitive changes. While several studies of adolescents have controlled for factors such as IQ (e.g., Fuhrmann et al., 2016; Lawrence et al., 2016), this does not preclude the possibility that face recognition improves as a by-product of more general object recognition and discrimination skills. Therefore, a key approach for examining the developmental trajectory of face-processing has been to assess children on both their object and face recognition skills.

Some reports suggest that face and object memory show different developmental trajectories, with face recognition maturing later than object recognition (Carey & Diamond, 1994; Diamond & Carey, 1977; see also Weigelt et al., 2014). This is known as the late maturity hypothesis. While most studies in the area have focused on children (under 12 years of age), at least two studies indicate that this developmental difference may continue into adolescence and even adulthood. Golarai et al. (2007) found that face memory showed continual improvements between childhood, adolescence, and adulthood; in comparison, age-related improvements were less pronounced for place memory and absent for object memory. De Heering et al. (2012) examined recognition of upright and inverted faces in 6-12 year old children and adults, and found that the effect of inversion (a commonly used measure of face-specific processing) increased between the oldest children and adults. By this account, face recognition in childhood (and even adolescence) relies on weaker, not fully mature face-specific processes, which should make it difficult to identify variability in face-specific abilities in this age range. This implies that individual differences (for example, super-recognition) that appear prior to adulthood are likely to be driven at least in part by object recognition abilities (due to the relative weakness of face-specific processes) – in other words, a pre-adult SR should show a limited dissociation between face and object recognition. Furthermore, indexes of face-specific processing, such as effects of inversion, should be reduced in comparison to adults who show similar levels of face recognition ability.

However, many studies that support this late maturity hypothesis have been criticized for methodological reasons (Crookes & McKone, 2009) – in some cases, floor and ceiling effects could have affected the conclusions (e.g., Carey & Diamond, 1994); in others, the lack of an appropriate comparison stimulus makes it difficult to determine whether the findings are specific to (or, in the case of inversion effects, disproportionate for) faces (Golarai et al., 2007; De Heering et al., 2012).

By contrast, other studies that have attempted to control for these issues have found similar patterns of development for memory of both faces and objects (e.g., Bennetts et al., 2017; see Crookes & McKone, 2009, for a review), suggesting that face recognition processes are mature quite early in life (before five years of age), and the improvement in face memory thereafter reflects the development of general cognitive skills (the early maturity hypothesis).

If this is the case, there are two important implications for the super-recognition literature: first, individual differences in the face processing system may also be present at an early age, and it should be possible to identify children and adolescents who fall outside the typical range of abilities for their age. This idea is supported by case studies of children with

DP, who show significantly worse face recognition than would be expected at their age (e.g., Dalrymple, Corrow, Yonas, & Duchaine, 2012; Dalrymple et al., 2014; Schmalzl et al., 2008; Wilson et al., 2010). Second, if face and object processing dissociate at an early age, it suggests that early differences in face recognition abilities will not necessarily be mirrored by differences in object recognition abilities. Notably, Dalrymple, Elison, and Duchaine (2016) reported several cases of childhood DP with normal object recognition, suggesting that it is possible to identify *face-specific* deficits from the age of five years. However, there are no studies to date that have attempted to examine whether cases of exceptional face-specific abilities – that is, an SR who does not show exceptional object recognition skills, and whose abilities can be attributed to face-specific processes – can occur before adulthood. The presence of face-specific super-recognition early in life would confirm that the wide range of face recognition abilities (e.g., Bowles et al., 2009; Germine et al., 2011) and the dissociation between face and object recognition observed in adulthood (e.g., Dennett et al., 2012; Wilmer et al., 2012) may also be present during development, and therefore offer support to the idea that face recognition can reach mature levels prior to adulthood (in line with the early maturity hypothesis).

Interestingly, this issue may be further complicated by findings that suggest different developmental trajectories for the memory and perception of facial identity. Behavioural studies that have suggested that the development of face recognition continues into adulthood (e.g., Germine et al., 2011; Susilo et al., 2013) have focused solely on memory-based tasks, leaving open the possibility that face perception is mature quite early. Weigelt et al. (2014) found evidence that face perception abilities were mature at an early age, but face memory underwent a more protracted period of development. Further, Dalrymple et al. (2014) recently described eight cases of DP in children younger than 13 years, and all had difficulties in facial perception as well as memory (in contrast, less than half the adult DPs tested showed impairments in face perception). The authors suggest that this may reflect different trajectories in the development of face perception and memory, with purely mnemonic deficits not being apparent or detectable until a later age, when face memory had developed fully. Consequently, it is important to examine both face memory and face perception abilities in developmental individual differences research, as it is possible that an individual might show exceptional abilities in one, but not the other. Furthermore, if it is the case that a SR excels at memory-based, but not perceptual tasks, it may act as an indicator of the age range at which the face memory system has matured sufficiently to support the identification of reliable individual differences.

It is also important to note that face perception can relate to aspects of facial information other than identity – for example, recognition of emotional expressions – and there is evidence to suggest these other aspects are processed by different mechanisms to those involved in identity (Bruce & Young, 1986; Duchaine & Yovel, 2015; Gobbini & Haxby, 2007). To date, super-recognition has only been assessed in relation to facial identity perception and memory, but examining whether SRs show superior facial expression processing in addition to identity processing may determine the locus of their superior face processing skills.

An alternative means of exploring the maturity of the face recognition system is to examine the emergence of critical visual strategies that may underpin super recognition. Eye-tracking has been used to examine individual differences in face recognition skills in adults. Eye movements are thought to be functional during the learning (Henderson, Williams &

Falk, 2005) and recognition (Althoff & Cohen, 1999; Luria & Strauss, 1978) of faces. Although few papers have examined eye-movement patterns with regard to individual differences in typical face recognition, Sekiguchi (2011) found that participants with better face recognition skills (who were not SRs) focused more on the eye region that those with poorer face recognition skills (who were not DPs), supporting the hypothesis that the eye region is thought to be particularly pivotal for the recognition of facial identity (Schyns, Bonnar & Gosselin, 2002; Slessor, Riby & Finnery, 2013; Van Belle, Ramon, Lefevre, & Rossion, 2010). According to these findings, one might predict that SRs spend more time looking at the eyes than typical perceivers, given this region seems to contain rich information about facial identity.

However, a recent paper from our laboratory refutes this hypothesis. Bobak et al. (2017) examined individual differences in eye-movement patterns in typical adults, those with DP and SRs. While we replicated previous findings that people with prosopagnosia (acquired or developmental) tend to avoid the eyes and sometimes spend more time looking at the mouth or external facial features (Bate et al., 2015; Schmalzl et al., 2008; Schwarzer et al., 2007; Stephan & Caine, 2009), the results of two experiments using different paradigms and stimuli sets indicated that SRs preferred to look at the nose. Interestingly, the time spent looking at the nose also correlated with face recognition ability in control participants. This work converges with findings from typical perceivers that identify the nose as an optimal viewing position in face recognition (i.e. the location of the first fixation that a person makes to a face) and preferred landing position (i.e. the location that participants fixate the most) (Hsiao & Cottrell, 2008). Similarly, Peterson and Eckstein (2012) found that the optimal viewing position on a range of face-processing tasks was below the eyes and towards the left side of the nose – in a remarkably similar position to that observed by Hsiao and Cottrell. Both sets of authors suggest that this viewing position may be the optimal location for holistic processing of the entire face to occur. This is an important issue when examining pre-adulthood cases of super recognition, as it permits investigation of the emergence of optimal processing strategies.

This paper presents an in-depth cognitive and eye-tracking examination of an adolescent with extraordinary face recognition skills, OB. First, we report data that confirms OB's superior face memory abilities; subsequently, we report a series of experiments that further investigate the nature of OB's face and object processing skills. Finally, we examine OB's eye movements in order to investigate whether the preference for the nose observed in adult SR cases replicates in OB, demonstrating that this strategy can emerge prior to adulthood.

Case Report

OB is a 14 year-old female who self-reported to our laboratory with exceptional face recognition skills, concurred by her mother. The family described many incidents where OB recognized people who she had only briefly encountered before, and subsequently viewed in very different contexts. For instance, her mother recalled an occasion when the family was watching a reality television program and OB recognized a pedestrian, who briefly walked past the camera, as a man she has seen in a local shop. OB reports that when she and her friends have looked at faces on the internet that have been morphed or disguised in some way, OB was the only one able to correctly identify the faces. OB and her sister noted that OB will have to take her particularly good face recognition abilities into account into social situations. For example, she may be introduced to someone for the first time that she recognizes from a chance sighting but she will have to remember that they will be unlikely to recognize her face. No other family members reported superior face recognition skills.

An initial neuropsychological screen indicated that OB had an estimated IQ of 118 (two-subtest version of the Wechsler Abbreviated Scale of Intelligence; Wechsler, 1999). In all experiments, her performance is compared to a group of 13 female control participants matched according to age (M = 15.04 years, SD = 0.8) and estimated IQ (see Table 1) (note that due to some data recording errors and time constraints, not all the control participants completed all tasks. The exact number of participants in the control group therefore varies between experiments, and is presented in the relevant sections of each investigation or in Tables 2 and 3). All participants reported no history of neurological, developmental or psychiatric conditions. OB and controls also performed in the normal range on a series of tests of basic visual perception (Snellen letter chart, Hamilton-Veale contrast sensitivity test, four subtests from the Birmingham Object Recognition Battery; Humphreys & Riddoch, 1993). These findings suggest that her superior face recognition ability is not a consequence of generally better intellectual abilities, or visuospatial processing (see Table 1). Finally, all participants were screened for signs of autism spectrum disorder (ASD), as ASD is known to affect face recognition (Weigelt, Koldewyn, & Kanwisher, 2012) using the Autism Quotient: Adolescent (Baron-Cohen, Hoekstra, Knickmeyer, & Wheelwright, 2006). OB and all controls achieved scores within the typical range (< 30) on this measure.

< *Insert Table 1* >

A series of experiments were conducted to further investigate the nature of OB's face and object processing skills. OB's performance in each experiment is compared to that of controls using the SINGLIMS procedure with one-tailed tests (Crawford & Garthwaite, 2002), or, when comparing her performance across multiple conditions, the Bayesian Standardized Differences Test (BSDT; Crawford and Garthwaite, 2007). The SINGLIMS procedure and the BSDT are modified t-tests designed to compare the scores of an individual case to a control group: each tests whether the case's score (or difference between scores, in the case of the BSDT) is significantly different to that of the controls, and provides an estimate of the abnormality of the score (i.e., the percentage of the population that would be expected to obtain a more extreme score than the case) as well as an estimate of effect size (Crawford, Garthwaite, & Porter, 2010). All research was approved by the institutional ethics review board.

Experiment 1

An initial experiment sought to confirm whether OB's face recognition skills were genuinely above those of her peers. In the adult SR literature, the extended form of the Cambridge Face Memory Test (CFMT+; Russell et al., 2009) is used to detect superior face recognition skills (Bobak, Bennetts, et al., 2016; Bobak, Dowsett et al., 2016, Bobak, Hancock, et al., 2016, Bobak et al., 2017; Russell et al., 2009; 2012). This test is a longer version of the standard Cambridge Face Memory Test (CFMT; Duchaine & Nakayama, 2006), which is a dominant test used worldwide to assess impaired and typical face-processing skills (e.g. Bate & Cook, 2012; Bennetts, Butcher, Lander, Udale, & Bate, 2015; Dalrymple & Palermo, 2016; DeGutis, Cohan, Mercado, Wilmer & Nakayama, 2012; Herzmann, Danthiir, Schacht, Sommer & Wilhelm, 2008; McGugin, Van Gulick & Gauthier, 2016; Yang, Susilo & Duchaine, 2016), and has demonstrated high reliability (Bowles et al., 2009; Wilmer et al., 2010) and both convergent and divergent validity (Bowles et al., 2009; Dennett et al., 2012; Wilmer et al., 2010, 2012).

Experiment 1 also examined whether OB's skills are face-specific or not, by measuring OB's performance with inverted (upside-down) faces. Inverted faces are generally thought to be processed in a different manner to upright faces – researchers have suggested that it is difficult to process spatial relationships between features, discriminate feature shape information, and integrate information from across the entire face at once (holistic processing) when a face is inverted (Maurer et al., 2002; McKone & Yovel, 2009; Piepers & Robbins, 2012, Richler, Palmeri, & Gauthier, 2012). These skills are thought to contribute to efficient recognition of upright faces (Maurer et al., 2002; McKone & Yovel, 2009), and some would go as far as to call these "face-specific" skills (Rossion, 2013; Yovel & Kanwisher, 2008). Consequently, inverted faces are thought to be processed more like objects (Freire, Lee, & Symons, 2000), and the inversion effect (the difference in performance between upright and inverted faces) has been taken as an index of "face-specific processing" in individuals with impaired face recognition (DeGutis, Cohan, Mercado, Wilmer, & Nakayama, 2012; Marotta, McKeeff, & Behrmann, 2002) and those with exceptional face recognition (Bobak, Bennetts, et al., 2016; Russell et al., 2009).

Method: In the traditional version of the CFMT (Duchaine & Nakayama, 2006), participants learn six target faces and in 72 trials are asked to choose which of three simultaneously presented faces is one of the targets. As the test progresses faces are presented from novel viewpoints and under different lighting conditions, and in a final section visual noise is added to the stimuli. The CFMT+ (Russell et al., 2009) replicates the CFMT exactly, but contains an additional 30 trials at the end. These items are particularly challenging: participants are tested on a variety of difficult transformations of the faces, including extreme viewpoint changes, modifications to emotional expression, and severe cropping of the images to exclude external cues to recognition.

Participants completed the CFMT+ twice: once in its original upright format, and then in an inverted format. Identical images are used in each. Participants always completed the upright version first, so that any additional exposure to the faces would not influence the critical upright score.

Results: OB out-performed the age-matched controls on the upright task by 6.04 SDs, making only three errors in the entire test (see Table 2). While this is strong evidence that OB is substantially better than her peers at face recognition, we were also interested in whether her scores are comparable to adult SRs, and whether OB would be considered a SR when compared to an adult control group (a more stringent test of her abilities). Consequently, we compared OB's performance to a group of six adult SRs who have already been reported in the literature (1 female, *M* age = 28.17 years, SD = 7.39; Bobak, Bennetts, et al., 2016), and the adult control group used in that study (N = 30, 15 female, *M* age = 25.90 years, SD = 4.50). The adult SRs scored between 92 and 100 on the CFMT+ (M = 97.17, SD = 2.93), compared to OB's score of 99. Single case comparisons confirmed that OB performed in a similar range to adult SRs, $t(5) = 0.72$, $p = .252$, $Z_{CC} = 0.78$, estimated percentage of adult SRs exhibiting a more extreme score = 25.26. OB significantly outperformed the adult control sample (M = 68.4, SD = 11.70), $t(29) = 2.57$, $p = .008$, $Z_{CC} = 2.62$, estimated percentage of adults exhibiting a more extreme score = 0.77. Given that OB's score exceeded both the age-matched control group and the adult control group, and is comparable to adult SRs who have already been reported in the literature (also see Russell et al., 2009), we took this as evidence that she clearly reaches the criteria for super recognition.

< *Insert Table 2* >

Interestingly, OB's performance was not significantly better than age-matched controls when the faces were inverted (see Table 2), resulting in an inversion effect (upright score – inverted score) that was significantly greater than the control group, $t(12) = 4.78$, $p < .0005$, $Z_{DCC} = 5.56$, estimated percentage of control population exhibiting a more extreme difference = 0.02. These findings suggest that OB's superior performance on the upright CFMT+ is a consequence of face-specific processing, rather than more general memory or visuospatial skills.

Experiment 2

Although the results of Experiment 1 provide strong evidence to suggest that OB's face recognition skills are superior to those of her peers and most adults, it is possible that this reflects a more general proficiency for within-class object identification; or particular skill with the CFMT format (as opposed to face recognition in general). Experiment 2 presents two tests examining these alternate explanations: first, a sequential matching task which included three categories of objects (faces, houses, and hands); and second, an object memory test matched in format to the CFMT: The Cambridge Cars Memory Test (CCMT; Dennett et al., 2012). This allowed us to more directly assess the hypothesis that OB's superior recognition skills are restricted to faces, and that her skills are not restricted to a single test of face memory.

Method: OB and controls completed a sequential same/different matching test used in previous work (Bate et al., 2015; Bobak, Bennetts, et al., 2016). In all three conditions (faces, houses, hands) the initial image was presented for 250 ms, and the subsequent image remained onscreen until the participant responded. In the face condition, the test images showed two face images from different viewpoints (front and 30-45°). Face images were taken from the CFMT (Aus) (McKone et al., 2011) and the Bosphorous face database (Savran et al., 2008), and were edited to remove external features. Houses were created using Realtime Landscaping Plus (Idea Spectrum Inc., 2012). Each house contained the same number of features (three sets of windows and a door), placed onto a constant background texture. The shape and location of the features, the luminance of the background texture, and the overall shape of the house varied throughout the set. As in the face condition, the test images presented the houses from two different viewpoints (front and 15°). Hand images were extracted from Bosphorus Hand Database (Dutağacı, Yörük & Sankur, 2008), and showed the palm and fingers of a hand. Images were chosen to exclude rings, watches, cuffs, or other identifying features. Test images showed the hands in two different positions (e.g., fingers splayed and fingers together), with the wrist pointing downwards (upright condition). Each category contained 32 pairs of images (16 same identity, 16 different identity). All pairs were presented twice upright and twice inverted. Trials were blocked by stimulus type, with upright and inverted trials presented randomly within each stimulus type. The order of blocks was randomized between participants. OB's performance was compared to the group of 13 control participants. Due to computer errors, only nine control participants completed the face matching condition (M = 15.36 years, SD = 0.39), whereas all 13 completed the hand and house matching conditions.

The CCMT follows the exact design of the original CFMT, but uses cars as stimuli. The CCMT has fewer trials than the CFMT+ (given it was based on the design of the CFMT), providing a maximum score of 72. The test was administered in upright and inverted formats, and again, the upright version was always administered first.

Results: The results of the sequential matching task are shown in Figure 1. Accuracy for the same and different trials in each category were combined into a single measure of sensitivity, *d'* (Macmillan & Creelman, 2005). An analysis of performance by control participants is presented in the Supplementary materials.

< *Insert Figure 1* >

OB performed significantly better than control participants when asked to match upright faces, $t(8) = 2.85$, $p = .011$, $Z_{CC} = 3.00$, estimated percentage of control population exhibiting a more extreme difference = 1.09. Similarly to findings for the CFMT+, OB did not differ from controls in the inverted face condition, $t(8) = 0.00$, $p = .5$, *ns*. Her inversion effect for faces was also significantly greater than controls, $t(8) = 2.01$, $p = .04$, $Z_{DCC} = 2.30$, estimated percentage of control population exhibiting a more extreme difference = 4.00, mirroring the increased inversion effect for the CFMT+. OB did not show a significant advantage over controls when asked to match upright or inverted hands or houses, *p*'s > .1 (see Figure 1). However, OB did perform above the mean for both object types, and the difference between OB's scores for upright faces and other objects was not significantly larger than controls, hands: $t(8) = 0.91$, $p = .194$, *ns*; houses: $t(8) = 1.12$, $p = .142$, *ns*. Once again, we compared OB's results to the adult SRs reported in Bobak, Bennetts, et al. (2016). The adult SRs had *d'* scores between 2.09 and 3.5 ($M = 2.83$, SD = 0.52) in the upright faces condition; and between 0.52 and 1.24 ($M = 0.73$, SD = 0.26) in the inverted faces condition. OB performed at a comparable level to adult SRs in the upright faces condition, $t(5) = 1.02$, $p = 0.17$, *ns*, and showed a similar sized inversion effect for faces, $t(5) = 1.02$, $p = 0.18$, *ns*.

OB achieved a score of 39/72 on the CCMT upright (a score that was more than one SD lower than that of controls), and 40/72 on the inverted test (a score that was very close to the control mean). In contrast to her performance on the CFMT+, OB's performance on the CCMT did not significantly differ to that of controls on either upright or inverted trials (see Table 2). OB's score on the original CFMT can be calculated from her CFMT+ score, permitting direct comparison of the two tests. In contrast to the CCMT test, she scored 72/72 on the upright version of the shorter test, and 39/72 on the inverted version. The difference between OB's performance on the CFMT and CCMT was significantly larger than controls, $t(10) = 4.65$, $p < .0005$, $Z_{DCC} = 5.09$, estimated percentage of control population exhibiting a more extreme difference = 0.46.

In sum, the findings from Experiment 2 offer some support for the notion that OB's superior recognition skills are specific to faces (enhanced inversion effect; larger difference between face and cars than controls). However, while OB was significantly better when matching faces than controls, she was also numerically better at matching hands and houses, and the difference between faces and objects was not disproportionate. This is unlikely to be a result of restriction of range, as all scores were substantially below ceiling (d' = 4.3). Therefore, it is possible that at least some of OB's performance on the matching test might be attributed to a general proficiency for matching upright objects.

Experiment 3

Experiments 1 and 2 support the prediction that OB has superior facial identity *recognition* skills. However, it is unclear whether her abilities extend to the *perception* of facial identity. That is, if no demands are placed on memory, is OB significantly better than her peers at extracting perceptual information relevant to facial identity? This is a pertinent question given a bulk of evidence suggesting that the two processes are dissociable (Barton, 2008; Barton, Cherkasova & Hefter, 2004; Bruce & Young, 1986; Davies-Thompson, Pancaroglu & Barton, 2014; Tippett, Miller & Farah, 2000), and that individuals at the bottom end of the face-processing continuum (i.e. those with prosopagnosia) have been separated into different subtypes that allow for spared or impaired facial perception skills (e.g. de Renzi, Faglioni, Grossi, & Nichelli, 1991). In the same vein, superior face recognition skills may result from enhanced face perception *or* face memory skills – while group analyses tend to support the idea that SRs overall show superior face perception, single case analyses indicate that not all adult SRs reported in the literature perform exceptionally well on face perception tasks (e.g., Bobak, Bennetts, et al., 2016; Bobak, Hancock et al., 2016; Russell et al., 2009). Furthermore, there are some reports of individuals who excel specifically at associative face memory without any evidence of enhanced perceptual processing (Ramon et al., 2016). While the individuals reported by Ramon et al. (2016) are not considered SRs, their capacity to excel at some aspects of face identification (i.e., face-name associations) but not others (perceptual processing) supports the distinction between the different stages of face recognition.

As discussed in the introduction, examination of this question in the context of an adolescent SR has particular implications for theories of the developmental course of face-processing, due to the proposed developmental dissociation between face perception and memory (e.g., Wiegelt et al., 2014). Thus, Experiment 3 examined OB's ability to perceive facial identity using the Cambridge Face Perception Test (CFPT; Duchaine, Germine, & Nakayama, 2007), a standardized test that has been used widely to examine face perception skills in DPs, the general population, and SRs (e.g., Bate & Cook, 2012; Bennetts et al., 2015; Bowles et al., 2009; Bobak, Bennetts, et al., 2016; Dalrymple & Palermo, 2016; Russell et al., 2009).

Method: In the CFPT, participants are asked to rearrange the order of a set of six test faces based on their similarity to a simultaneously-presented target face. Each of the test faces has been morphed towards the target face by different degrees. The CFPT contains 16 trials; eight are presented in an upright format and eight are inverted. Participants have one minute to sort each set. Scores reflect the deviation of the final arrangement to the correct order (i.e. a higher score indicates worse performance).

Results: OB performed significantly better than controls on the upright trials of the CFPT, outperforming her peers by over two SDs (see Table 2). As found in previous experiments, there was no significant difference between OB and controls on inverted trials. However, unlike in the CFMT+ and sequential matching tasks, OB did not show a disproportionate inversion effect in the CFPT, $t(12) = 1.30$, $p = .220$, *ns*. Although her performance was numerically worse, OB's performance on both the upright and inverted conditions of the CFPT was not significantly different to the adult SRs reported in Bobak, Bennetts, et al. (2016) (upright: $M = 18.33$, SD = 4.80; inverted: $M = 54.83$, SD = 10.52), upright $t(5) = 1.86$, $p = 0.12$, *ns*, inverted $t(5) = 1.69$, $p = 0.15$, *ns*. BSDT revealed that OB's inversion effect was not significantly different to adult SRs, $t(5) = 0.17$, $p = 0.43$, *ns*.

Performance on this task, in combination with the findings from the sequential matching task in Experiment 2, provide some evidence that enhanced face perception skills may be underpinning OB's superior face recognition ability. This finding is not unusual – while it is not universal, many SRs show excellent performance on face perception tasks (e.g., Bobak, Bennetts, et al., 2016; Russell et al., 2009), and within the general population scores on the CFPT and CFMT are significantly correlated (Bowles et al., 2009). However, OB's superior performance in Experiment 3 is not nearly as pronounced as in Experiment 1 – this could suggest that OB excels at mnemonic tasks more than perceptual ones.

Experiment 4

While at least some evidence of enhanced facial identity perception has been presented thus far, it is unclear whether this ability extends to non-identity aspects of face perception, such as the processing of emotional expression, age, and gender. In other words, does OB show superior abilities for all aspects of face recognition, or is her super-recognition specific to identity? To date, no published reports have assessed non-identity aspects of face processing in SRs. However, there are numerous reports of individuals with DP who show typical recognition of facial expression, age, and gender (e.g., Chatterjee & Nakayama, 2012; DeGutis, Chatterjee, Mercado, & Nakayama, 2012; Duchaine, Parker, & Nakayama, 2003; Humphreys, Avidan, & Behrmann, 2007), suggesting that identity may be processed separately from other, non-identity-based facial cues. Likewise, traditional models of face-processing (e.g. Bruce & Young, 1986; Haxby, Hoffman, & Gobbini, 2000) posit at least some dissociation between the processing of identity and non-identity cues. However, there are also commonalities between different tasks – for example, both expression and identity recognition involve some level of holistic processing (e.g., Calder, Young, Keane, & Dean, 2000; Palermo et al., 2011). Therefore, it is possible that identity and non-identity face tasks involve some shared mechanisms or processes which precede separate processing stages (Palermo et al., 2011). If these shared mechanisms underpin OB's super-recognition, it may be that she shows exceptional performance on all face processing tasks; on the other hand, if the locus of her exceptional abilities is after the dissociation between abilities, we would expect OB to show typical non-identity processing. Consequently, Experiment 4 presents a series of tests which examine whether OB excels at non-identity face processing.

We adopted two well-used tests of facial expression recognition: the Ekman 60 Faces test (Young, Perrett, Calder, Sprengelmeyer, & Ekman, 2002) and the Reading the Mind in the Eyes Test (RMITE; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001) – a more complex test of expression recognition that involves only the eye region of the face. These tests were chosen because they have both been used frequently to assess individual differences in the recognition of facial expression (Ekman: Habota et al., 2016; Moulier et al., 2016; Unoka, Fogd, Füzy & Csukly, 2011; Verdejo-García, Rivas-Pérez, Vilar-López & Pérez-García, 2007; RMITE: Bate, Parris, Haslam, & Kay, 2010; Peterson & Miller, 2012; Rodrigues, Saslow, Garcia, John, & Keltner, 2009).

Experiment 4 also included tests of facial age and gender perception. For this investigation we used the age and gender sub-tests from the Philadelphia Face Perception Battery (PFPB; Thomas, Lawler, Olson, & Aguirre, 2008). The measure has been shown to have good test-retest reliability and specificity for internal feature processing, and the subscales have also been demonstrated to have good divergent validity (Thomas et al., 2008). The PFPB has been used to investigate typical (Thomas et al., 2008) as well as impaired (Németh, Zimmer, Schweinberger, Vakli & Kovács, 2014; Thomas et al., 2008) face perception abilities.

Method: The Ekman 60 Faces test consists of 60 trials in which participants are shown a face and asked to choose which of six basic emotions is being expressed (anger, disgust, fear, happiness, sadness, or surprise). Each face is viewed for 5 seconds, but participants have an unlimited time to make their response.

The RMITE test has 36 trials, in which participants are shown the eye region of a face and asked to choose which of four given thoughts or feelings is being expressed. There is no time limit to make a response, and participants are given a definition of each thought or feeling if they are unsure of its meaning. The RMITE assesses more subtle emotional states than the Ekman 60 Faces test – for example, discriminating between jealous, panicked, arrogant, and hateful expressions.

Two sub-tests from the PFPB were selected for use in this task, assessing the facial perception of age and gender. In both sub-tests the faces were drawn from a set of computer-generated images, and pilot testing was used to select 75 trials that were somewhat ambiguous, in order to avoid ceiling effects (see Thomas et al., 2008, for further details). In the age sub-test, participants are simultaneously presented with two faces, and are asked to select which one appears older. In the gender sub-test, participants are presented with a single face and asked to indicate whether the person is male or female. Stimuli remained onscreen until participants respond.

Results: OB achieved a score of 50/60 on the Ekman 60 Faces test, which was less than one SD above that of controls (see Table 2). She scored 23/36 on the RMITE test – a score that was almost identical to the control mean (see Table 2). These tests indicate that OB's expression recognition skills are within the normal range.

On the subtests of the PFPB, OB scored 68/75 on the age test (a result that was less than one SD above that of controls), and 64/75 on the gender test (a score that was only half a SD above control performance) (see Table 2). Overall, these results concur with the findings from the two assessments of OB's expression recognition skills. In sum, the results from Experiment 4 suggest that OB's exceptional memory for facial identity does not reflect a general enhancement of facial processing. Rather, it appears that OB is particularly good at extracting and using identity-specific cues.

Experiment 5: Eye-tracking

The experiments described above indicate that OB has superior specialised facial identity recognition skills that may at least in part be underpinned by enhancements in the perception of facial identity. That is, she may be using enhanced perceptual strategies to extract information that assists with later identification. However, the work reported so far does not tell us anything about the regions of the face from where this information may be extracted. Indeed, certain facial areas may hold rich information that is critical to optimal face recognition performance (Peterson & Eckstein, 2012), or may represent preferred viewing spots from which most information can be extracted (Peterson & Eckstein, 2013). Pertinently, existing eye-tracking work has identified two regions of the face that may be particularly informative for facial identity recognition: Investigations using both typical participants and those with prosopagnosia indicate that the eye region may be critical for recognition **(**Orban de Xivry, Ramon, Lefèvre & Rossion, 2008; Schmalzl et al., 2008), whereas other work suggests more central regions (i.e. the nose) may be critical fixation points for optimal face recognition (Hsiao & Cottrell, 2008; Orban de Xivry et al., 2008; Peterson & Eckstein, 2012). Notably, the optimal points of fixation for identity, expression, and gender discrimination are subtly different (Peterson & Eckstein, 2012); furthermore, research using the Bubbles technique has shown that typical individuals use different facial information to complete different face processing tasks (e.g., Schyns et al., 2002). Therefore, a tendency to fixate more consistently or longer on one region of the face (e.g., the region optimal for recognition), might explain why OB excels only at certain aspects of face processing (i.e., the same area may not be optimal for expression recognition).

Our existing work with adult SRs supports the importance of central fixations for face recognition, at least for SRs: these individuals look at the nose to a greater extent than controls (Bobak et al., 2017). Our final experiment therefore sought to investigate whether the same trend will emerge even in an adolescent SR, adopting an eye-tracking paradigm that we have previously used in our work with this age group (Bate et al., 2015) and in adults who meet the criteria for super recognition (Bobak et al., 2017).

Method: Participants were tested in a quiet environment, whilst sitting approximately 60cm from the screen with their heads placed within a chin rest. The Eyelink 1000 system (SR Research Ltd, Canada) was used to record eye movements, using a video-based pupil/corneal reflex tracking device sampled at 2000 Hz with spatial accuracy of between 0.25 and 0.5 degree of visual angle. Prior to the experiment eye fixations were calibrated.

Each participant viewed 48 facial images from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist, Flykt, & Őhman, 1998). Three images were presented for each of 16 individuals (eight male), one displaying a happy expression, one a neutral expression and one a sad expression. Each face was presented in colour on a grey background for 5 seconds and the order of presentation was randomised. As the aim of the experiment was to measure the time spent dwelling on inner features, faces were uncropped (i.e., hair was included in all images) so that this would not cue participants towards these parts of the face. Images were aligned and adjusted to 762 pixels in height and 562 pixels in width. A centrally positioned fixation dot was presented before the stimuli appeared to control the initial point of retinal attention. Faces were then presented in the centre of the screen, where the area below the right eye overlapped with location of the previously presented fixation cross. Given this method might direct the first fixation to key regions of interest, first fixations were excluded from all analyses.

Participants were asked to remain attentive to the faces and freely explore them. We did not set a specific task because we wanted to mimic natural occurrences when people incidentally encounter faces – indeed, inexplicable recognition of incidentally and only briefly seen faces is core to the definition of super recognition. Further, the emotional expression manipulation was adopted merely to retain participants' attention and to mimic natural settings where faces are rarely seen with neutral expressions. Pertinently, previous studies investigating the scanning of faces displaying different emotional expressions have reported consistent findings regardless of the instructions given to participants. For instance, Pelphrey et al. (2002) found similar eye movement patterns in typical participants and those with autism spectrum disorder, regardless of whether they were instructed to "look at the faces in any manner your wish" or to "identify the emotions portrayed in the faces". We therefore did not require participants to make an explicit judgment about each face in order to keep the conditions as naturalistic as possible.

Eye Movement Parameters and Statistical Analyses: Eye movements were analysed using Eyelink Data Viewer software (SR Research Ltd), which allows periods of fixation to be identified and user-defined areas of interest to be determined within the images. Three areas of interest were drawn onto each face, covering the eyes, nose, and mouth (see Bate, Haslam, Tree, & Hodgson, 2008). Data were averaged for each facial expression and for all trials (see Table 3), and the proportion dwell time elicited to the eye, nose and mouth regions was calculated. Control data is taken from an age- matched group of 11 females (M age = 15.1 years, SD = 0.9), as reported in Bate et al. (2015). This work found that typical perceivers spent less dwell time on the eyes for happy compared to neutral or sad faces, and more dwell time on the mouth for happy compared to neutral or sad faces (see Table 3 for descriptive statistics, and for a full report of analyses on the control data see Bate et al., 2015).

Results: The main analysis focused on dwell time: we examined whether OB spent significantly longer examining specific areas of the face (eyes, nose, mouth) than control participants for each emotion category. Strikingly, differences between OB and controls were only noted for the nose region: OB spent significantly more time examining the nose for neutral and sad faces, in addition to the overall analysis (see Table 3). This pattern of findings converges with previous work indicating that the nose may be critical in face identification, perhaps because it is the optimal viewing position for holistic processing (Hsiao & Cottrell, 2008; Peterson & Eckstein, 2012).

However, OB's pattern of feature exploration did not differ according to emotional expression for the proportion dwell time spent on the eyes and mouth (all *p*s > .05). Nevertheless, she did follow the same trend as control participants by spending more time on the mouth for happy compared to neutral or sad faces, $F(1,15) = 7.880$, $p = .013$, $\eta_p^2 = .344$. This is likely the reason why the happy condition was the only one in which OB did not spend significantly more time on the nose than controls (although the mean time she spent on the nose was approximately two SDs above that of control participants). It is fairly typical for individuals to spend longer looking at the mouth region in happy faces (e.g., Eisenbarh & Alpers, 2011). Hence, OB still appears to follow normal trends in her patterns of feature exploration according to emotional expression, but retains her overall increased bias towards the nose. This evidence indicates that the nose may be a critical region underpinning superior face recognition, and the bias towards it emerges even in adolescence.

< *Insert Table 3* >

A secondary analysis aimed to reveal whether OB's bias towards the nose was driven only by the first movements of the eyes (which previous work have deemed to be the most critical in face-processing, e.g. Hsaio & Cottrell, 2008; Peterson & Eckstein, 2012) or is evident across the entire time course of scanning. To this end, we examined the sequential distribution of fixations to the nose across all faces. Data showing the frequency with which OB and controls fixated the nose in the first five eye movements made to each face are presented in Table 4 (note: in the present study the first movement of the eyes corresponds to the second fixation, given the location of the fixation cross in this study, and the subsequent removal of all first fixations from analysis. Consequently, Table 4 presents data for fixations two through six). OB directed significantly more second fixations to the nose than control participants, $t(10) = 3.47$, $p = .003$, , $Z_{CC} = 3.63$, estimated percentage of control population exhibiting a more extreme difference = 0.30, yet this effect disappeared from the third fixation onwards, p's > .10. It can therefore be concluded that OB's preference to look at the nose is restricted to the critical first eye movement made while viewing a face.

< *Insert Table 4* >

Discussion

OB shows exceptional face recognition skills across multiple tasks (CMFT+, sequential same/different matching, CFPT). These skills do not appear to extend to low-level visual processing (BORB tests), object recognition (CCMT, sequential matching) or other non-identity aspects of face recognition (emotion, age, gender). Despite the fact that adolescents, on average, tend to perform significantly worse than adults on tests of face recognition (e.g., Fuhrmann et al., 2016; Picci & Scherf, 2016), OB's performance on multiple tests is in a similar range to other adult SRs who have been reported in the literature (e.g., Bobak, Bennetts, et al., 2016; Bobak, Dowsett et al., 2016, Bobak, Hancock, et al., 2016; Russell et al., 2009). Furthermore, OB shows an enhanced effect of face inversion across several tests (CFMT+, sequential matching), which is comparable in size to inversion effects observed in adult SRs. OB's performance on an eye-tracking task is also in line with previous results from adult SRs tested in our lab (Bobak et al., 2017) – she spent substantially more time than control participants examining the nose region of the face. In short, OB's performance across multiple tasks suggests that she is a super-recogniser: the youngest reported in the literature to date.

OB's case may inform us about the development of individual differences in face recognition. Despite some evidence that face recognition continues to develop throughout adolescence and into adulthood (e.g., Germine et al., 2011; Aylward et al., 2005; Golarai et al., 2007, 2010; Pallett & Dobkins, 2013; Peters et al., 2013; Scherf et al., 2007, 2011, 2013), the current results, along with research on developmental prosopagnosia in children (Dalrymple et al., 2016), suggest that individual differences in face recognition can be apparent at a relatively young age. Most pertinently, these individual differences are not driven purely by object processing skills or general cognitive skills, as predicted by the late maturity hypothesis. Rather, OB's pattern of performance supports the idea that differences in face recognition abilities in this age range can be face-specific, in line with the early maturity hypothesis.

The assertion that OB's superior recognition skills are face-specific is supported by two sets of results. First, as mentioned above, OB did not perform significantly above average on any tests of object recognition (cars, houses, or hands). A caveat to this is that OB did perform numerically better than her peers across most of the object matching conditions in the sequential matching task, and the comparison between upright faces and objects did not reveal disproportionately good performance for faces when compared to houses or hands. These results could indicate that OB has a general proficiency for matching upright objects, at least in tasks with minimal memory demands. Taken alone, this finding offers some support to the idea that individual differences prior to adulthood might be a result of more general object recognition skills (in line with late maturity hypothesis). However, OB also performed within the normal range when asked to remember, sort, and match inverted faces, suggesting that her skills are isolated to upright faces. In line with previous studies on adult SRs (e.g., Bobak, Bennetts, et al., 2016; Russell et al., 2009), OB showed an enhanced inversion effect (the difference between performance with upright and inverted faces) on several face recognition tests (CFMT+, sequential matching), which suggests that face-specific skills underpin her super-recognition. Furthermore, OB's inversion effects were comparable to adult SRs in all tasks for which comparison data was available, which suggests that her face-specific processing skills have already reached adult levels.

What aspects of face processing does OB excel at? Research on adult SRs suggests that the cognitive origins of super-recognition, like DP, are likely to be heterogeneous (e.g., Bobak, Bennetts, et al., 2016; Bobak, Hancock, et al., 2016). One way which SRs may differ is the locus of their abilities – as discussed in Experiment 3, many researchers have proposed a distinction between perceptual and mnemonic processes supporting face recognition (e.g., Bruce & Young, 1986; De Renzi et al., 1991; Weigelt et al., 2014). An initial assessment of OB's behavioural results would suggest that she performs substantially better than her peers and shows a large inversion effect when the task involves a memory component (as in the sequential matching task and the CFMT+), but her exceptional face recognition abilities are less pronounced for purely perceptual tasks: OB showed much smaller effects in the CFPT compared to the CFMT+, and no enhanced inversion effect for the CFPT.

However, a more detailed analysis of OB's results reveals a different picture. While OB's performance in the CFPT was not as dramatic as the CFMT+, her results were nonetheless significantly better than her peers. Furthermore, OB showed different patterns of eye movements to faces, despite the absence of any memory requirement during the eye-tracking task. An alternate interpretation of these results is that OB is more efficient than her peers at extracting facial information (perhaps due to a more optimal pattern of eye movements to faces), but this is only apparent in very challenging tests, such as those that require recognition across substantial changes in facial appearance (the CFMT+) or after very brief presentation of the face (sequential matching task). In contrast, the CFPT allows participants to view the faces for up to a minute. It is possible that the less challenging viewing conditions in the CFPT allowed our control participants to "catch up" to OB and perform relatively accurately. As we did not instruct participants to respond as quickly as possible in the CFPT, it would not be appropriate to compare reaction times on this task, however, future work with SRs should incorporate multiple measures to take into account potential differences in speed and efficiency of processing, as well as accuracy.

Notably, OB's proficiency with facial information does not extend to all face processing tasks. In contrast to her performance on identity processing tasks, OB scored within one standard deviation of the mean for all non-identity tasks (two emotion processing tasks, age, and gender). This supports the idea that identity and non-identity cues are processed by at least partially separable pathways (Bruce & Young, 1986; Duchaine & Yovel, 2015; Gobbini & Haxby, 2007), and the locus of OB's abilities falls after any shared processing mechanisms. However, the current study is the first to examine whether SRs excel at non-identity-based face processing tasks, and this finding does not preclude the possibility that some SRs may also show exceptional abilities for non-identity information – for example, it is possible that an individual could excel at the early stages of face processing (which contribute to both identity and expression recognition). However, while the Ekman 60 faces and RMITE are sufficient to determine impairment or examine performance in the typical range of abilities (such as OB and controls in the current study), they are not ideal for detecting exceptional performance (more than 2 SDs above the control mean). Therefore, testing this proposition may require the use of more challenging non-identity tasks such as those developed by Palermo, O'Connor, Davis, Irons, and McKone (2013), or Young et al. (1997).

This is the second study (after Bobak et al., 2017) to find that SRs spend a longer time than controls looking at the nose region of the face during a free-viewing task. While OB showed the same general tendency as controls to modulate her fixations depending on facial expression, she also demonstrated a general bias towards the nose region. This bias occurred early during viewing: OB was significantly more likely to fixate on the nose region following her first eye movement (i.e., on her second fixation), but this tendency disappeared for subsequent fixations. These results support previous suggestions that the nose region is optimal for integrating identity information across the face (Hsiao & Cottrell, 2008; Peterson

& Eckstein, 2012), and reiterate the importance of early fixations for efficient identification. Notably, this finding does not detract from other evidence that emphasizes the importance of the eye region for face recognition in typical perceivers (e.g., Sekigucki, 2011) – in fact, our control participants demonstrated a strong bias towards the eyes in most conditions. Rather, it suggests that those individuals who excel at face recognition may adopt different, potentially more optimal, strategies than typical perceivers (in line with Bobak et al., 2017). However, OB's behavioural results indicate that increasing fixations to the nose does not necessarily improve performance in all face processing tasks (e.g., expression and gender discrimination). This is in accordance with the finding that the optimal fixation point for various tasks is slightly different, and raises the possibility that an over-reliance on information from one area (in this case, the nose) may lead to exceptional performance on some tasks (identity discrimination), without necessarily affecting performance on others (e.g., expression recognition). It would be particularly interesting to examine eye movements from individuals who excel at multiple face processing tasks, compared to those who show very specific abilities (such as OB), and to track eye movements during specific tasks (e.g., expression or identity processing) to examine whether the bias towards the nose region is modulated or eliminated under different task demands.

One aspect of these results that remains unclear is how stable these exceptional abilities are. There are relatively few studies on the stability of face recognition between childhood or adolescence and adulthood: some adult cases of DP have recounted difficulties that began in childhood (e.g., de Haan, 1999; Duchaine, Murray, Turner, White, & Garrido, 2009; Duchaine, Yovel, Butterworth, & Nakayama, 2006); other cases that have originally been reported as children have shown a consistent deficit when followed up after several years (see Dalrymple et al., 2012). Similarly, adult SRs recount experiences from childhood, which suggest their super-recognition arose early in life (e.g., Bobak, Bennetts, et al., 2016; Russell et al., 2009). However, there may be cases where children have simply shown an unusual developmental trajectory, and have gone on to develop relatively normal face recognition skills (see Bennetts et al., 2017; Dalrymple et al., 2014 for discussion). Similarly, it is possible that OB has shown a different developmental trajectory to her peers, in which her face processing matured particularly early. In that case, we would expect her face-specific processing to remain relatively stable in the future. Alternatively, given that face memory and the neural systems underpinning face recognition in the typical population continue to change in adolescence, it is possible that OB's performance might also change with time. If it is the case that OB's abilities develop further (or decline) as she enters adulthood, it would lend support to the idea that the face processing system undergoes a protracted period of plasticity and development that lasts at least until late adolescence, and perhaps adulthood (Germine et al., 2011; Susilo et al., 2013).

In sum, OB is an adolescent with exceptional face recognition abilities – a super-recognizer. Her pattern of results in tests of face memory, face perception, and eye-movements to faces mirror those found in adult SRs. This is the first report of a SR prior to adulthood, and confirms that a wide range of individual differences in face recognition are present at a relatively young age, even while the neural systems underpinning face recognition are still maturing. Furthermore, these individual differences are not driven purely by general cognitive abilities – multiple lines of evidence confirm that OB's abilities are face-specific. While OB is the youngest SR reported to date, it is important to note that these individual differences may be apparent even in very young children – the lack of younger cases is likely a result of the fact that children are unlikely to have good insight into whether their abilities are “normal” or “exceptional” (even adults have relatively limited insight into their face recognition abilities; Palermo et al., 2017), so it is unlikely that they will be able to self-identify as super-recognisers. This difficulty is compounded by the relative scarcity of developmental individual differences research, combined with a lack of properly normed and psychometrically valid tests of face and object processing for young children. Recently, though, several child-friendly tests have been developed to identify cases of DP in childhood (e.g., Bennetts et al., 2017; Croydon et al., 2014; Dalrymple et al., 2014) – it is possible that these resources will make it possible to identify SRs at a much earlier age, and facilitate longitudinal studies that examine the stability of individual differences in face recognition throughout development.

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Table 1: OB's background neuropsychological screen. "BORB" refers to the Birmingham Object Recognition Battery (Humphreys & Riddoch, 1993).

		Age-matched controls			Modified *t*-test[a]			
	OB	Mean	SD	n	*t*	*p*	% population more extreme than OB	Estimated effect size (Z_{CC})
IQ[b]								
Verbal (*T* score)	**59**	51.09	7.44	11	1.02	.166	16.60	1.01
Performance (*T* score)	**59**	52.82	7.49	11	0.79	.224	22.40	0.82
Full-2 IQ	**118**	103.18	11.12	11	1.28	.115	11.54	1.33
BORB								
Length Match	27/30	25.28	1.73	12	0.96	.180	18.00	0.99
Size Match	27/30	26.08	1.93	12	0.46	.328	32.79	0.48

Orientation Match	25/30	24.67	2.06	12	0.15	.440	44.02	0.16
Position of Gap Match	35/40	35.50	2.11	12	-0.23	.412	41.20	-0.24

[a]All analyses were conducted using Crawford and Garthwaite's (2002) modified *t*-test for single-case comparisons. All results are for one-tailed tests. [b]IQ was assessed for OB and most controls using the two-subtest version of the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). The IQ of one additional control participant (not included figure in Table 1) was tested using equivalent subtests from the Wechsler Adult Intelligence Scale IV (Weschler, 2008), and was within the range of our other control participants.

Table 2: OB's performance on tests of face and object processing. "CFMT+" refers to the Cambridge Face memory Test – Long Form (Russell, Duchaine, & Nakayama, 2009), "CCMT" refers to the Cambridge Car Memory Test (Dennett et al., 2012), "CFPT" refers to the Cambridge Face Perception Test (Duchaine et al., 2007), "Ekman 60" refers to the Ekman 60 Faces Test (Young et al., 2002), "RMITE" refers to the Reading the Mind in the Eyes Test (Baron-Cohen et al., 2001), and "PFPB" refers to the Philadelphia Face Perception Battery (Thomas et al., 2008).

		Age-matched controls			Modified *t*-test[a]			
	OB	Mean	SD	n	*t*	*p*[b]	% population more extreme than OB	Estimated effect size (Z_{CC})
Face and object memory								
CFMT+ upright	**99/102****	59.08	6.61	13	5.82	<.001	0.01	6.04
CFMT+ inverted	**53/102**	46.54	4.89	13	1.27	.114	11.36	1.31
CFMT+ inversion effect[c]					4.78	<.001	0.02	5.56
CCMT upright	**39/72**	47.27	5.66	11	-1.40	.096	9.60	-1.46

CCMT inverted	**40/72**	40.18	8.42	11	-0.02	.492	49.20	-0.02
Perception of facial identity								
CFPT upright[d]	**28****	39.85	5.57	13	-2.05	.031	3.14	-2.13
CFPT inverted[d]	**74**	72.62	14.75	13	0.09	.465	53.52	0.09
CFPT inversion effect[c]					1.30	.110	10.99	-1.39
Non-identity face perception								
Ekman 60	**50/60**	45.90	6.98	10	.56	.294	29.46	0.59
RMITE	**23/36**	23.63	3.80	11	-.16	.438	43.85	-0.17
Age perception (PFPB)	**68/75**	60.30	7.85	10	.94	.187	18.70	0.98
Gender perception (PFPB)	**64/75**	59.18	8.53	11	.54	.300	30.02	0.57

[a]Tests were conducted using the SINGLIMS computer program, which uses methods outlined in Crawford and Garthwaite (2002) and Crawford, Garthwaite, and Porter (2010). [b]Results are for a one-tailed test. [c]Inversion effects are calculated by comparing the difference in OB's performance on upright and inverted trials to the difference in control participants' performance on upright and inverted trials, using the Revised

Standardized Differences Test (implemented in the RSDT.exe computer program) (Crawford & Garthwaite, 2005). [d]CFPT scores measure deviation from an ideal arrangement, not accuracy. Therefore, a lower score indicates better performance (see Duchaine et al., 2007). **Indicates performance that significantly differs from controls.

Table 3: The proportion of dwell time that OB spent looking at each facial region in the eye-tracking study, compared to age-matched controls. Cells in bold indicate a significant difference.

	OB	Age-matched controls			Modified *t*-test[a]			
		Mean	SD	n	*t*	*p*	% population more extreme than XX	Estimated effect size (Z_{CC})
Happy								
Eyes	**48.09**	49.92	23.97	11	-0.07	.943	47.16	-0.08
Mouth	**17.80**	19.73	10.12	11	-0.18	.859	42.94	-0.19
Nose	**31.28***	14.59	8.75	11	1.83	.098	4.89	1.91
Neutral								
Eyes	**53.11**	57.72	20.71	11	-0.21	.836	41.78	-0.22
Mouth	**9.48**	12.37	9.48	11	-0.29	.776	38.82	-0.31

	Nose	**34.23****	14.70	7.63	11	2.45	.034	1.71	2.56
Sad									
	Eyes	**50.43**	54.17	24.21	11	-0.15	.885	44.27	-0.15
	Mouth	**8.42**	12.27	8.38	11	-0.44	.669	33.47	-0.46
	Nose	**38.63****	15.96	8.48	11	2.56	.028	1.42	2.67
Overall									
	Eyes	**50.54**	53.94	22.87	11	-0.14	.890	44.48	-0.15
	Mouth	**11.90**	14.79	9.13	11	-0.30	.768	38.40	-0.32
	Nose	**34.71****	15.09	7.87	11	2.39	.038	1.91	2.49

[a]All analyses were conducted using Crawford and Garthwaite's (2002) modified *t*-test for single-case comparisons. All results are for two-tailed tests. **Indicates performance that significantly differs from controls. *Indicates performance that is approximately two SDs from the control mean but does not reach significance on statistical comparisons.

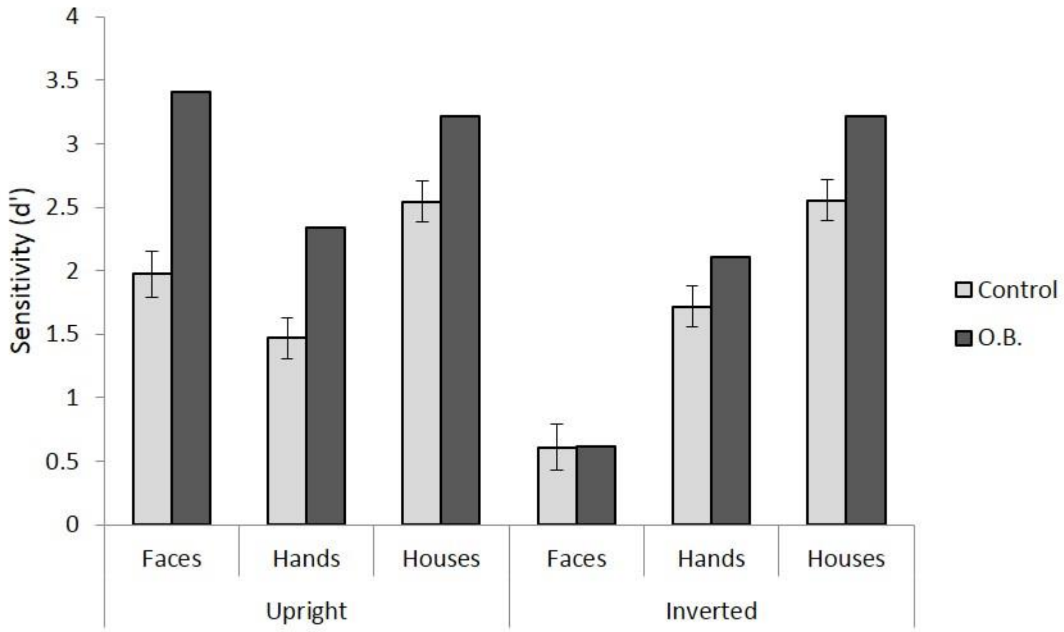
Table 4: Frequency with which OB and controls fixated the nose during fixations two to six in each trial. Column labels indicate fixation number.

	2[a]	3	4	5	6
Control Mean	3.00	5.36	2.73	2.64	2.36
Control SD	3.86	4.70	1.76	2.23	2.27
OB	17**	6	2	0	0

[a] The first fixation to the face has been removed from all analyses given it overlaps with the location of the initial fixation cross. Consequently, we have only presented data for fixations two through six (i.e., the first five fixations after the initial eye movement made in each trial).

**Indicates performance that significantly differs from controls.

Figure 1:



Sensitivity (d')
4
3.5
3
2.5
2
1.5
1
0.5
0
Faces
Hands
Houses
Faces
Hands
Houses
Upright
Inverted
Control
O.B.

Figure captions:

Figure 1: Accuracy (d') of OB and control participants on the object test (Experiment 2).

Error bars show +/-1 SEM